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NBSIR 73-141

Fire Endurance Tests of Plywood on Steel Joist Floor Assemblies, With and Without Ceiling

(Test Numbers 492, 497)

H. Shoub, B. C. Son

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

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Final Report

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NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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by

H. Shoub
and
B. C. Son

ABSTRACT

Fire endurance tests were conducted on two floor/ceiling assemblies intended for use in modular housing. One assembly simulated the combination of the floor of an upper story module with the ceiling assembly of the module beneath; the other assembly, the floor of a first floor module over a ceilingless crawl or foundation space.

The floors were of plywood deck with vinyl or carpet overlay on light gage steel "C" joists. In the floor-ceiling assembly, the ceiling was separately supported on its own joists, contained simulated HVAC* duct work and a layer of glass fiber batt insulation. During the tests which were conducted generally in accordance with the requirements of ASTM E 119-71, Fire Tests of Building Construction and Materials, the floors were loaded to represent the dead weight of structural parts bearing on them and a live load application of 40 psf. The test results are valid only for floors of similar construction loaded at or below the stress level developed by this loading.

Failure of the floor with the protective ceiling assembly occurred by flame-through to the unexposed surface at 29 min., with extensive structural failure (collapse under load) following at 33 min. The

*HVAC - Heating, Ventilation and Air Conditioning

unprotected floor over the crawl space had a flame-through at 3 1/4 min., and structural failure following at 3 3/4 min.

Key Words: Fire test; Floor assembly; Floor-ceiling assembly; Housing systems; Modular construction; Operation BREAKTHROUGH; Steel framing; Steel joist floor

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1.0 INTRODUCTION

The fire endurance of two plywood and steel joist floor assemblies, one designed for the first floor module of a low-rise multifamily residential structure, the other as an upper story floor over a ceiling covering a module below, was investigated in tests conducted by the Fire Research Section of the National Bureau of Standards.

Although the use of stacked factory-built modules for residential occupancies is becoming more prevalent, there have been very few fire tests made on structural elements of two living unit modules positioned one above the other. This type of construction is illustrated in figure 1. These tests were conducted to examine the effect of several innovative features of modular floor structures on the overall fire performance of the assemblies. The structural steel members of the floors were of a type not widely used for joists in residential construction and the performance under fire conditions of their method of attachment to the perimeter framing of the floors was unknown.

The tests, which were conducted generally in accordance with the requirements of ASTM Standard E 119-71, Fire Tests of Building Construction and Materials[1/], were sponsored by the Department of Housing and Urban Development in an evaluation program of housing systems submitted under Operation BREAKTHROUGH.

1/ Standard Methods of Fire Tests of Building Construction and Materials, American Society for Testing and Materials Designation E 119-71, available at 1916 Race Street, Philadelphia, Pa. 19103

2.0 DESCRIPTION OF TEST SPECIMENS

2.1 Floor Assemblies

The floors for the two tests were of similar construction and will be described together with a separate section to present the ceiling assembly used in one of the tests.

The details of the floors are shown in figures 2, 3a and 3b, the latter two including the attached ceiling. The floor framing was factory-built, each in three sections, which were assembled with splice plates and covered with plywood and finish flooring at the NBS test facility. This was necessary due to size and handling constraints in the test furnace building. The overall floor size was 11 ft 9 in. by 17 ft 11 in. The 3/4-in. thick tongue-and-groove, Douglas fir underlayment grade plywood flooring, was attached at 12-in. spacing along the perimeter and in the field with 1 1/8-in. long hi-lo bugle head screws. Half the plywood surface of each floor was covered with vinyl roll flooring, half with pad and carpet. The vinyl flooring was 5/64 in. thick. The carpeting, 3/8-in. Nylon pile on 1/8-in. jute backing, was laid over a 1/4-in. rubberized hair pad.

The floors were built into perimeter channels of 6 1/8-in. by 1 3/4-in. 18 ga. galvanized cold rolled steel. Floor joists, 6-in. by 1 3/4-in. 18 ga. cold rolled steel "C" sections, were welded to the perimeter channels at 24-in. on centers with 20 gage clip angles. The assembled framing can be seen in figure 4. On the foundation space (or crawl space) floor a steel reinforcing strap, 3-in. wide, 24 ga., was welded transverse to the bottom of the joists at the midspan.

As a means of simulating the floor and walls, stub walls of 5/8-in. Type X gypsum board attached to 3-in. "C" studs to an overall height of 18-in. from the bottom of the joists to the top of the wall were erected on the perimeter of the floor. Further, reinforcement was provided in the form of cross-bracing members at the top of the stud walls (figures 2 and 3a) in simulation of the rigidity provided by a ceiling structure.

2.2 Ceiling

The ceiling assembly as shown in figures 5 and 6 was also constructed with simulated perimeter walls to reduce the conditions at the top of a housing module above. The stub walls were 24-in. in height with the ceiling joists placed to allow about a 6-in. space above them for duct work and batt insulation.

The ceiling joists, 3-in. by 1 3/4-in. 18 ga. cold rolled steel "C" sections, similar to the floor joists, were spaced on 24-in. centers and welded to the perimeter channel. A 3-in. wide 24-ga. continuous bracing strap was welded to the top of the joists at their midspan. A 2-in. glass fiber blanket was placed over the joists, passing over the duct work and ceiling diffuser as shown in figures 3a and 3b. The ceiling surface was 5/8-in. Type X gypsum boards attached with 1-in. S-12 bugle head screws spaced at 6-in. on centers on the perimeter of the boards and 12-in. on centers in the field.

As with the floor assemblies, the ceiling assembly frame was fabricated by the housing system producer in three sections, and was joined by splice plates at the test facility. The specimen for the fire test

was assembled by joining the floor and ceiling assemblies with bolts through bearing plates on the abutting ends of the stub wall studs. The bolts were on 24-in. centers, and were located adjacent to the studs.

3.0 TEST METHOD AND INSTRUMENTATION

The floor and floor-ceiling assemblies were tested in the NBS floor furnace with the underside of the floor or the ceiling exposed to a fire controlled to give an average temperature in the furnace in accordance with the time-temperature schedule specified in the ASTM E 119 standard. The temperature within the furnace was determined from the readings of 12 thermocouples protected and positioned in the furnace chamber as required by the test standards.

According to the standard, the fire endurance of a floor or floor-ceiling assembly is the time required to reach the first occurrence of any one of the following criteria of failure:

1. Inability to sustain the load.
2. Passage of flame or gas through the structure to the unexposed surface hot enough to ignite cotton waste.
3. A temperature rise of 250 degrees F (139 degrees C) average or 325 degrees F (181 degrees C) at one point above the initial temperature on the unexposed surface.

When positioned for the test, the 17-ft 11 in.-long floor specimens had only nominal clearance in the 18-ft long furnace opening. The floor width of 11 ft 9 in., however, was 15 in. less than the furnace width. To provide for this, the floor assemblies were installed to one side of the opening at the top of the furnace, with an I-beam for support of the

side not against the furnace wall. Suitable fire resistive material was placed to protect the beam and provide closure of the space. As the auxiliary beam and filler were not part of the test structures, they were designed so as not to contribute to, or be affected by, the fire exposure.

Loading of both floors was the same, applied with concrete blocks to a weight of 51.4 psf. This represented a design live load of 40 psf, and a dead weight of supported structure of 11.4 psf (not including the 3.6 psf weight of the floor itself). The actual construction dead load on the ceiling assembly was approximated by the installation of ductwork and insulation.

Deflections of the floors during the test were measured along the longitudinal centerline, at the midpoint of the assembly and at the quarter points. Wires with suitable pointers and scales were attached at the three check points to provide visual indication as well as automatic recording (through potentiometers) of the movement of the floor surfaces.

For the floor over the foundation space, temperature measurements were made on the unexposed surface only. This was accomplished with 12 Chromel-Alumel (Type K) thermocouples disposed in an almost symmetric pattern over the vinyl and carpet coverings, as shown in figure 7. Each thermocouple was covered with an asbestos pad (6- by 6- by 0.4-in.) as specified in the ASTM E 119 standard. Temperature readings indicated by the thermocouples, including those in the furnace, were recorded at 2-min. intervals for subsequent processing and plotting by computer.

The floor-ceiling assembly had thermocouples on the interior members of the structure and under the covering material as well as on the unexposed surface, although the failure by temperature rise is determined only by the condition on the unexposed surface. Thirteen thermocouples placed on the floor covering were distributed as indicated in figure 8, which also shows the disposition of the thermocouples under the covering and in the structure, a total of 62 for the assembly. Those on the unexposed surface were covered with asbestos pads as described above. The remainder were uncovered, and were attached with screws to the adjacent structural parts or ductwork.

4.0 RESULTS OF TESTS

4.1 Floor Over Foundation Space

Failure of the floor structure over the foundation or crawl space was observed at 3 min. 15 sec. after start of the test when flames penetrated the unexposed surface. At 3 min. 45 sec. the entire floor collapsed into the furnace under the superimposed load of concrete block, probably as a result of failure of the welded joints at the perimeter framing.

The ASTM E 119 fire test standard requires compensation for fire exposures deviating from the standard time-temperature relation only if indicated failure times are 1/2-hr. or greater. As the fire exposure severity in this case was appreciably greater than that required by the standard (figure 9), it was appropriate to apply corrections for the times to the two modes of failure despite their brevity. Applying these corrections estimates to the results, the end point times become 3 min. 30 sec. and 4 min. 5 sec. for flame through and failure to sustain load, respectively.

Maximum and average temperature rises on the unexposed surface (over vinyl floor covering, figure 10; over carpeting, figure 11) were low, and did not approach the limits defining failure by transmission of heat. The recorded data indicated little or no effect of the flame penetration, probably because this occurred at one end of the floor, somewhat away from the thermocouples.

At 2 min. after start of the test the exposed plywood surface was charred, with general flaming at 2 1/2-min. Significant bowing of the floor was noted as early as 1 min. of test time, and increased rapidly until final collapse. Deflections were measured as follows:

Time (min)	(South) 1/4 Pt (in.)	Center (in.)	(North) 1/4 Pt (in.)
Initial	0	0	0
1	1.2	1.8	1.4
2	2.6	3.6	2.5
3	6.0	7.6	5.5
3:45	Collapse		

A view of the top or unexposed surface of the collapsed floor is presented in figure 12.

4.2 Floor-Ceiling Assembly

For the floor-ceiling assembly, failure occurred at 29 min. after start of the test by passage of flame through to the unexposed surface. At 33 min., local collapse of the assembly was observed at the end away from the ductwork and diffusers. As can be seen in figure 13 the actual fire exposure severity was slightly greater than that specified in the

standard and a correction of approximately 1 min. should be added to the noted failure.

Average and maximum temperature rises on the unexposed surface were not significant, with the maximum rise not exceeding 50 degrees C on the carpet at the end of the test, as can be seen in figure 14. Surface temperature rises in the area covered with vinyl flooring did not approach those over the carpet. As before, the flame through occurred in an area away from the thermocouple locations.

Temperature rises on the steel joists and adjacent structure are illustrated in figure 15 (average) and figure 16 (maximum). Similar rises in the area of the ceiling duct are shown in figure 17, giving the average temperature changes. Maxima in this location were not significantly higher. Temperature rises through the assembly at locations not at joists were noted to be somewhat lower than those indicated for the thermocouples at sections through the joists.

No significant deflection of the floor surface was noted until 26 min. after start of the test, when a downward movement of 0.7 in. occurred at one of the quarter points. This rapidly increased so that a 30 1/2-min., prior to complete collapse, the deflection at this point was approximately 8 in. At the same time, the deflection at the midpoint was 2 in., at the other quarter point, 1 in.

A log of the observations made during the test on the floor-ceiling assembly is given in Appendix I.

5.0 DISCUSSION OF RESULTS

The dimension of the shorter side of the floor assemblies tested, 11 ft 9 in., was slightly less than the 12 ft required by the ASTM E 119 standard. However, the size tested was representative of that to be used in the actual modules.

The uniform distribution of heat in the furnace is reflected in the temperature gradients measured at the five steel joist locations. At these points, the maximum and average temperature rises were of a similar pattern, with the maxima only moderately higher than the averages, indicating the absence of wide variations of exposure. If large differences in furnace temperature had been present these would have been reflected in the temperatures on the test structure.

For the unprotected floor assembly over a foundation space, failure occurred at less than 5 min. with the indicated furnace temperature considerably less than 1000°F. This can be explained by a lag in the furnace temperature readings which are based on thermocouples in heavy iron pipes. The actual furnace temperature was considerably higher during the early stage of the test. Of greater significance than the loss in yield strength of the structural elements at elevated temperature was their rapid expansion which caused the welded attachment to the perimeter framing to break within a few minutes after start of the test.

In floor-ceiling assembly, the gypsum board ceiling provided protection to the ceiling and floor joists, the latter being further shielded by the insulating blanket over the ceiling. Failure in this test depended upon heat penetration of the protective layers. Opening

of the gypsum board ceiling may have been precipitated by torsional buckling of the asymmetrical "C" ceiling joists.

The loading applied to the floor assemblies in these tests was based on calculated dead loads for the structure and an estimated occupancy live load, but did not necessarily develop the maximum allowable working stresses in the structural members. Thus, the results of these tests may be made applicable only to similar floor assemblies with spans and loads such that the stresses developed do not exceed those developed in these constructions.

6.0 SUMMARY AND CONCLUSIONS

In a fire test of a floor assembly consisting of 3/4-in. plywood on unprotected steel "C" section joists, failure by flame through occurred at 3 1/4 min. and failure by inability to sustain an applied load occurred at 3 3/4 min. after start of the test. A primary cause of the failure was the breaking of the weld joints between the joists and their supporting perimeter frame. Failure of a similar floor assembly, but with a protective gypsum board ceiling, was noted at 29 minutes by flame through and at 33 minutes by load failure following destruction of the ceiling and its insulating overlay.

In both tests, torsional buckling of the "C" sections was apparently a contributing, and perhaps the principal, factor in the failures. This movement probably accelerated destruction of the welds. The uneven movement of the structural elements could have opened the ceiling in the assembly so constructed, allowing early heat penetration, and acted similarly on the plywood floors, producing flame through conditions in

both tests at times less than ordinarily experienced with the given thickness of wood.

The load applied to the floors was 40 psf and the results should be applied only to floors of similar construction loaded to develop stresses not exceeding those developed in this assembly.

APPENDIX I

Log of Fire Test of Floor - Ceiling Assembly

Time Min:Sec	Observation
01:00	Considerable smoke in furnace, probably from pyrolysis of paper on the gypsum board.
05:00	Gypsum board paper on exposed side consumed.
07:00	Sheet metal diffusers warping slightly.
08:00	Smoke on top at one corner, indicating possible combustion of the binder in the glass fiber insulation.
10:00	Some smoke at all edges adjoining stub walls.
12:00	Diffusers appear to have dropped about 1-in.
16:00	Diffuser near end of ceiling still moving down; gypsum board panel at same end moving out.
21:00	Diffuser nearer to center descended about 1 1/2-in. Apparent flaming on gypsum board on fire side, from joints and cracks; joint spackling falling out.
23:00	Smoke mainly at edges on unexposed side.
24:00	A gypsum board panel opening, and appears ready to fall.
25:00	Gypsum board panel fell into furnace, exposing the glass fiber insulation blanket.
29:00	Furnace full of flames; gypsum board ceiling falling in; glass fiber insulation melting; much smoke coming through top of specimen. Flame through.
32:00	Considerable flaming at one end of floor; fire exposure terminated.
33:00	One end of floor assembly fell into furnace.

APPENDIX II

SI Conversion Units

In view of present accepted practice in this country in this technological area, common US units of measurement have been used throughout this paper. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measurements which gave official status to the metric SI system of units in 1960, we assist readers interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 meter
1 ft = 0.3048 meter

Mass

1 lb = 0.45 Kilograms

Stress

1 psf = 47.88 newton/meter^2
1 psi = 0.332 newton/meter^2
1 plf = 13.45 newton/meter

Temperature

Temperature in °F = 9/5 (temperature in °C) + 32°F

LIST OF ILLUSTRATIONS

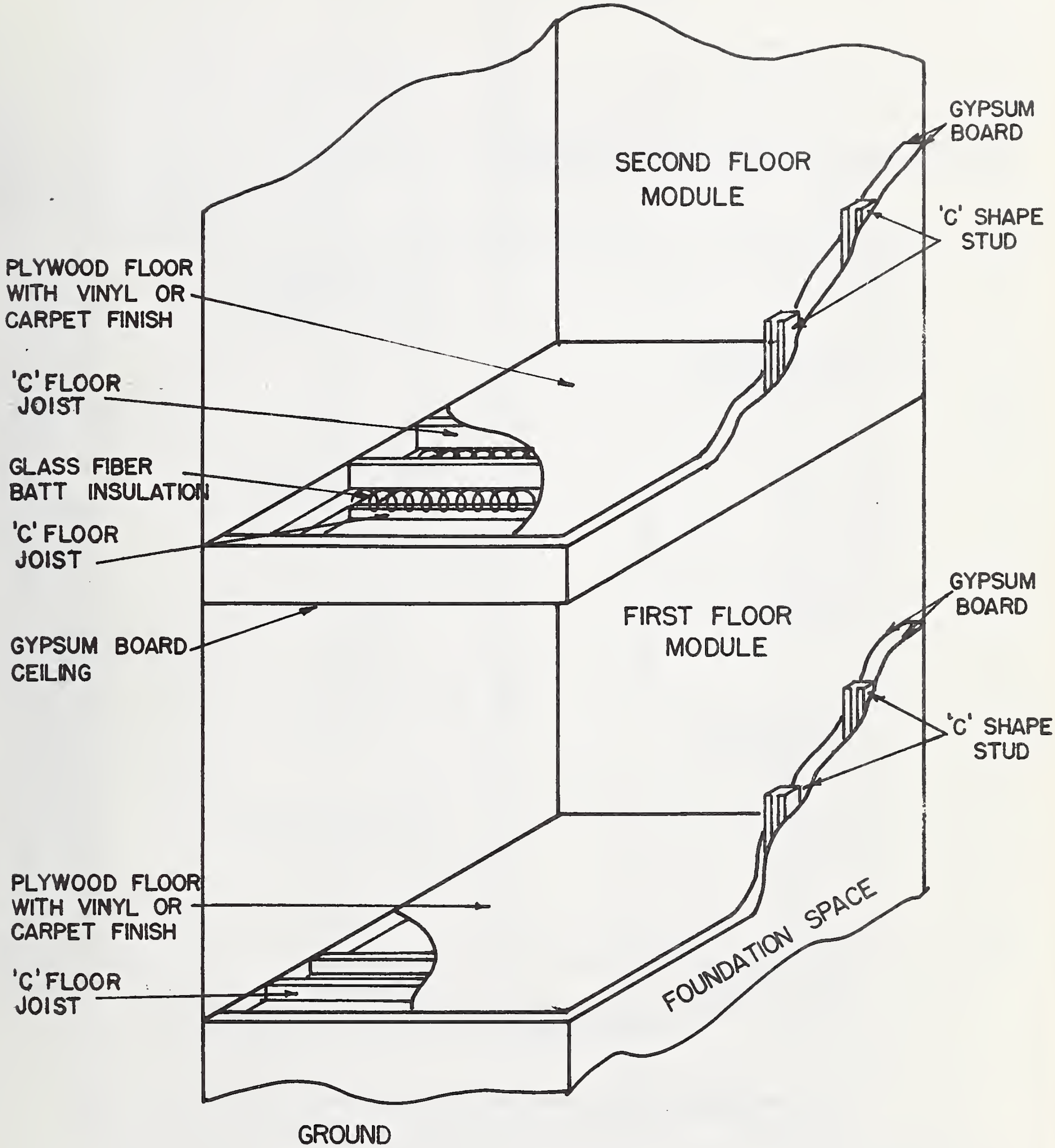


Figure 1 - Sketch of Module Positioning

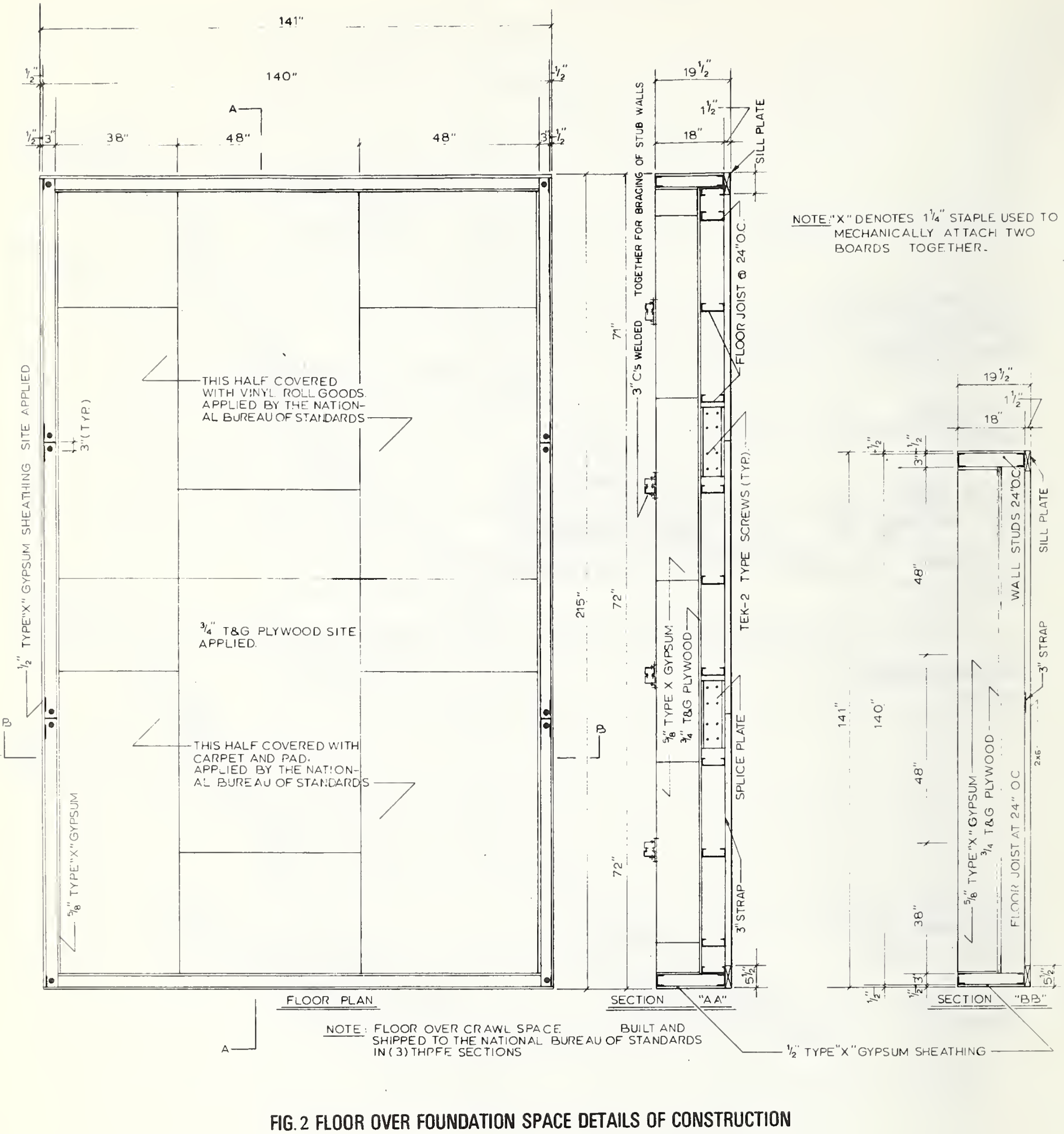


FIG. 2 FLOOR OVER FOUNDATION SPACE DETAILS OF CONSTRUCTION

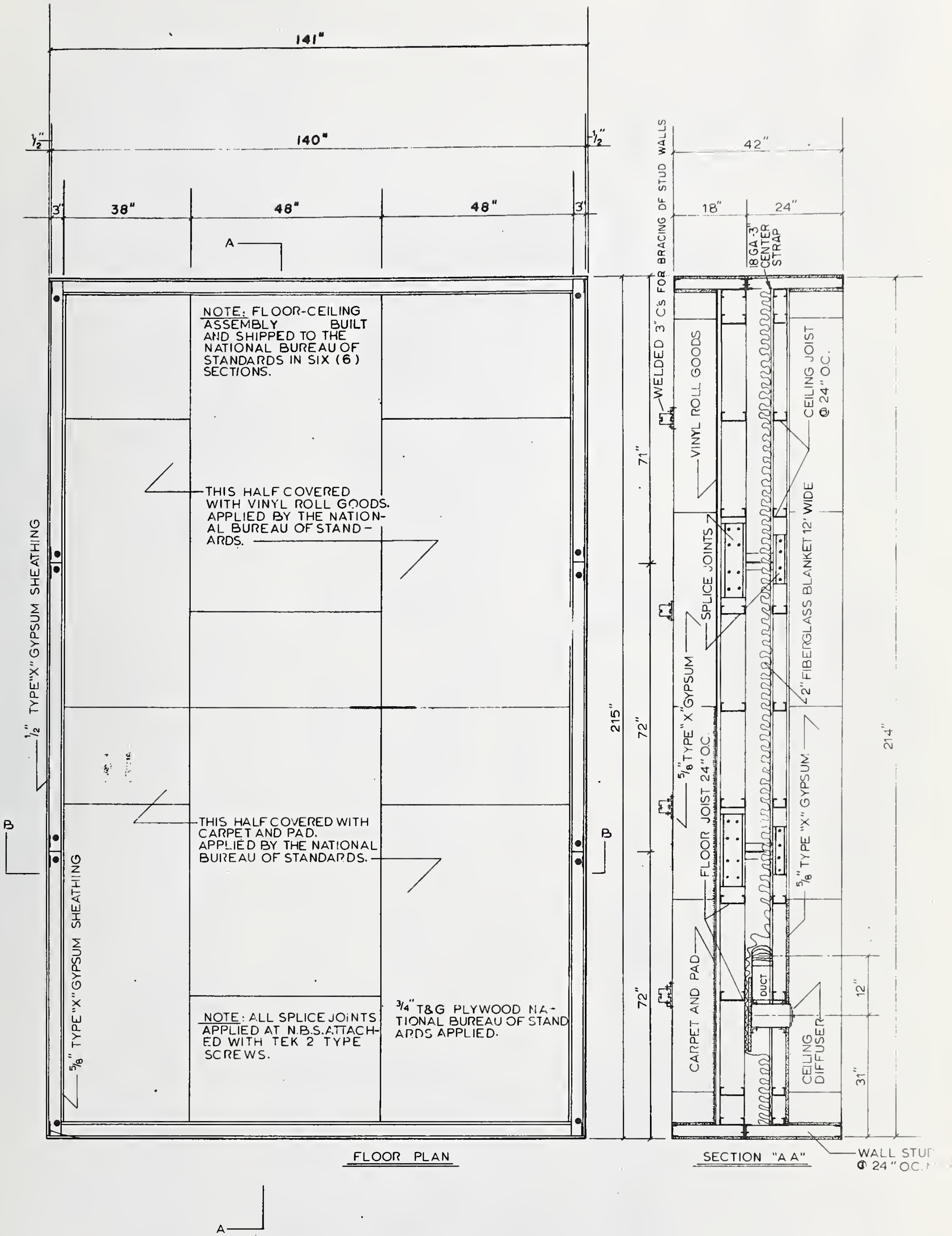


FIG. 3a FLOOR–CEILING ASSEMBLY CONSTRUCTION

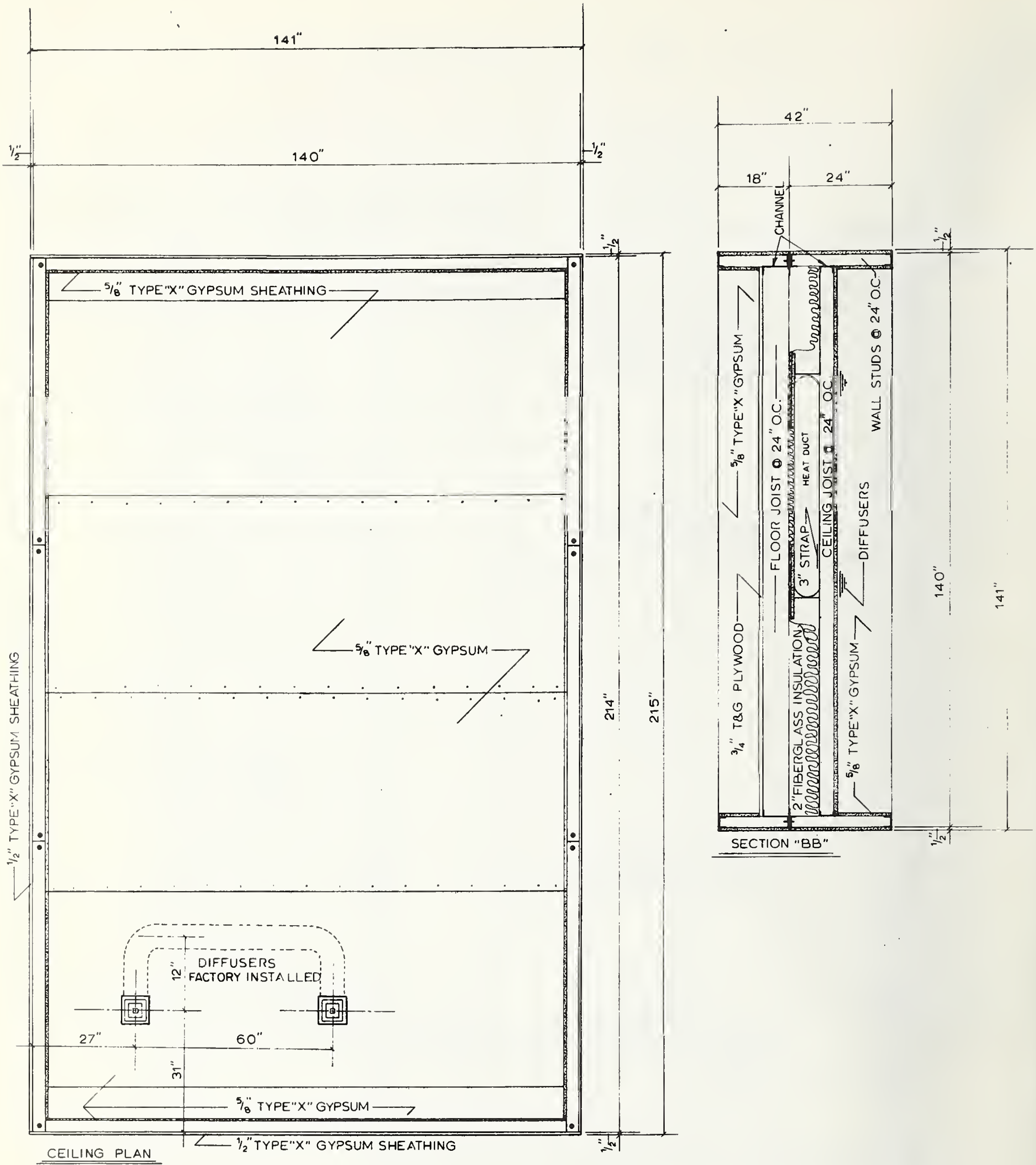


FIG. 3b FLOOR–CEILING ASSEMBLY CONSTRUCTION

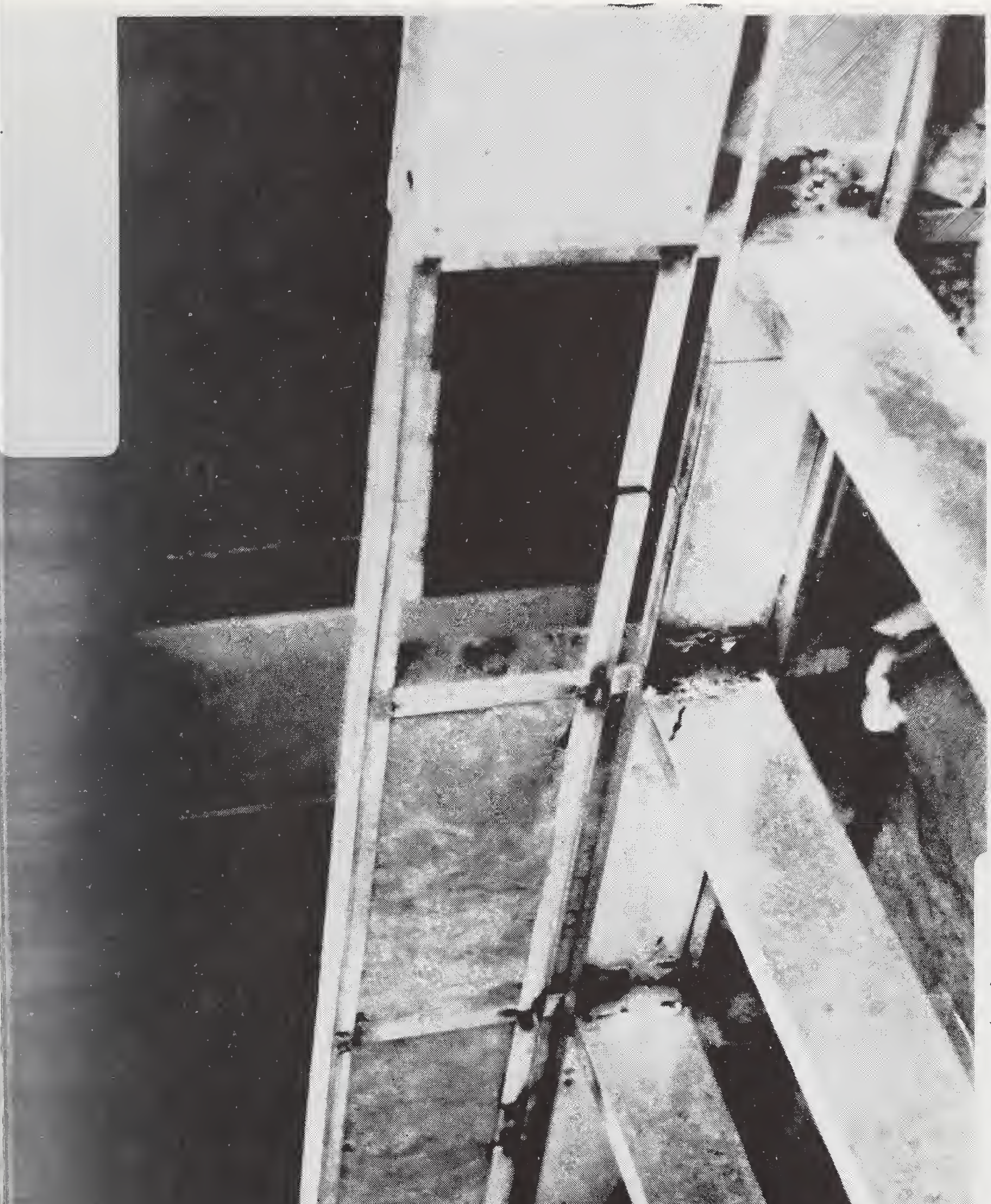


Figure 4. Floor Framing Showing Construction of Stud Walls, and Ceiling Insulation

Figure 5. Floor-Ceiling Assembly
Ceiling Framing showing duct.

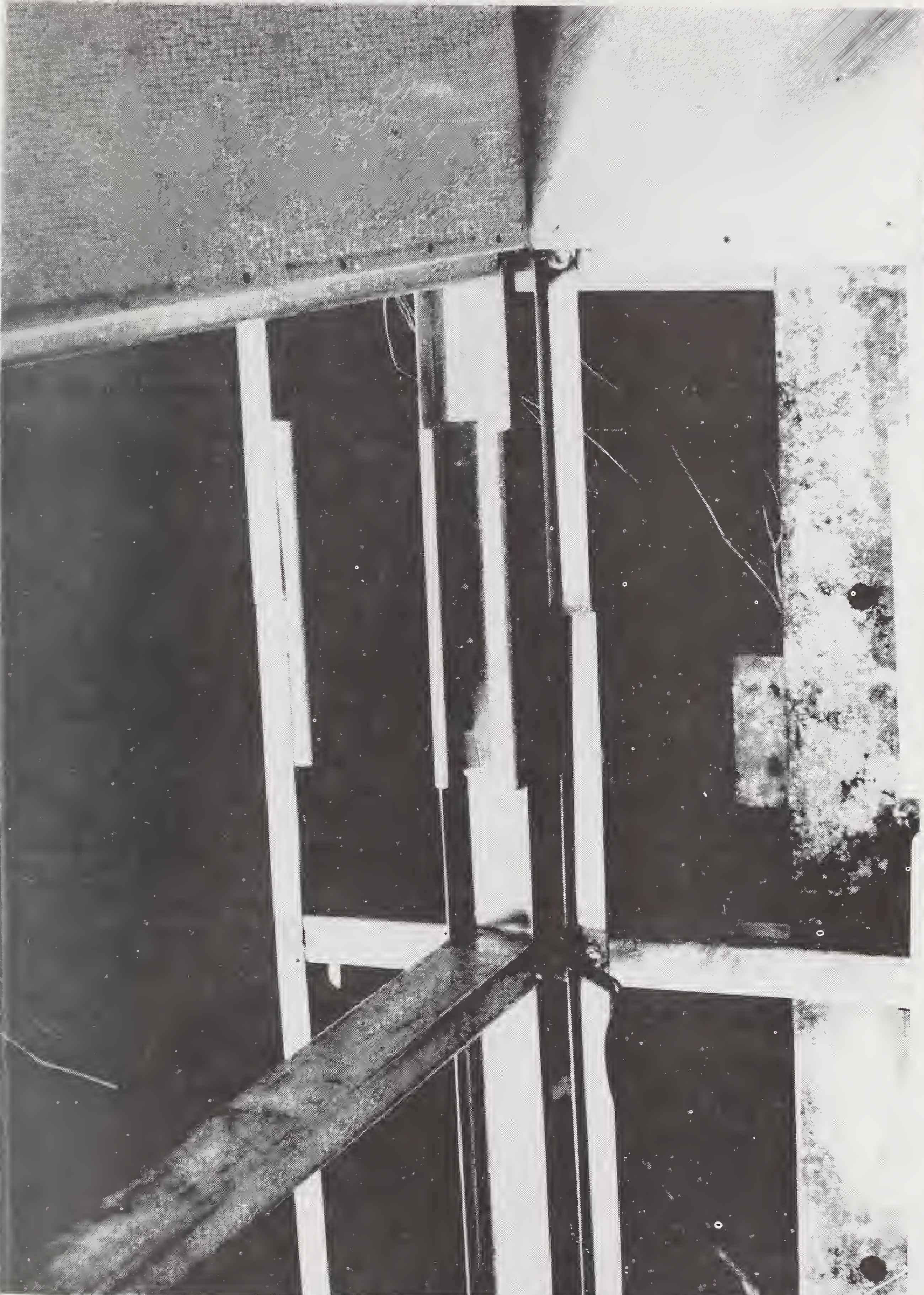


Figure 6. Ceiling Assembly--View of Framing, Partially Covered Ceiling, and Stud Wall

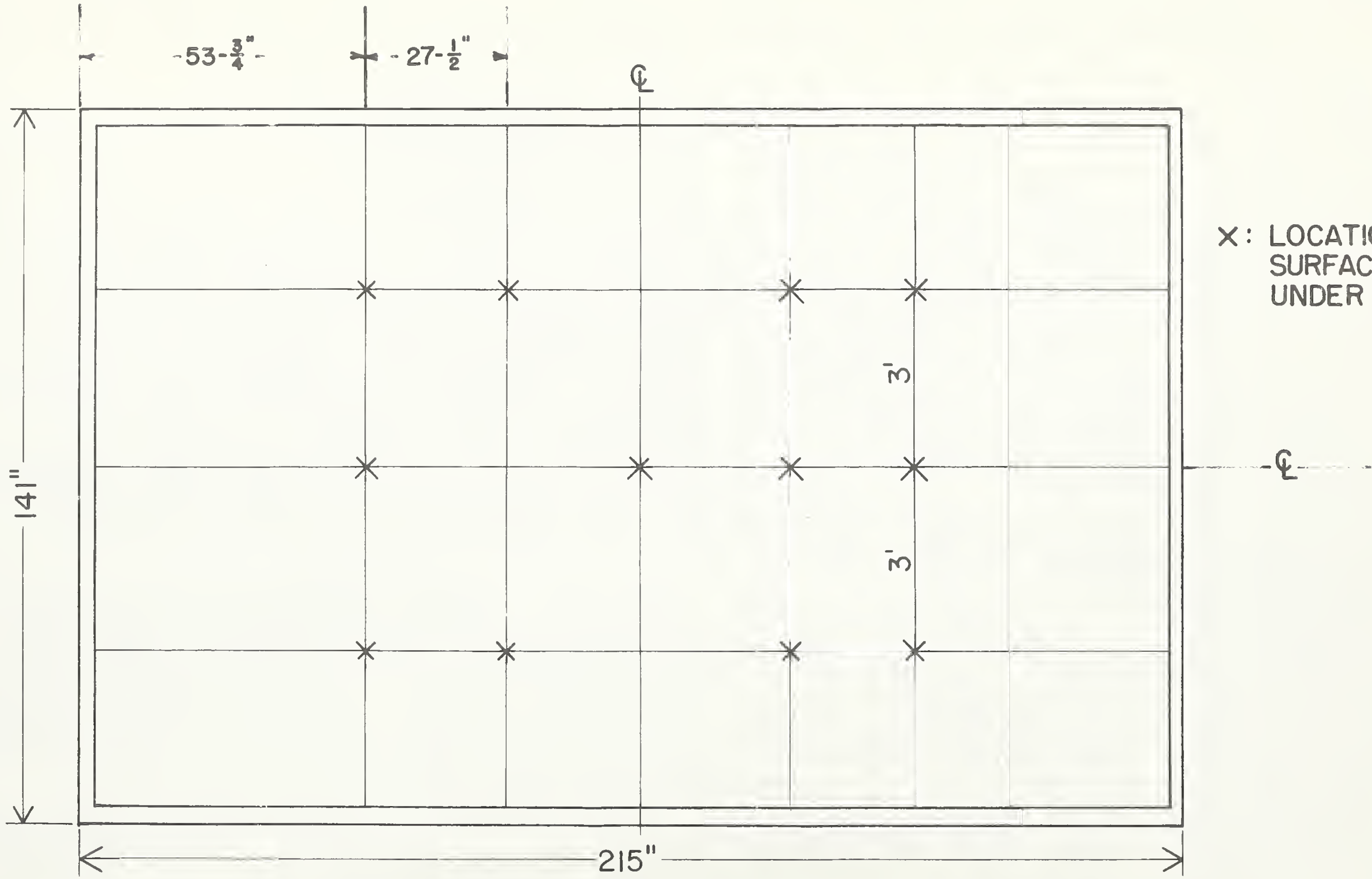
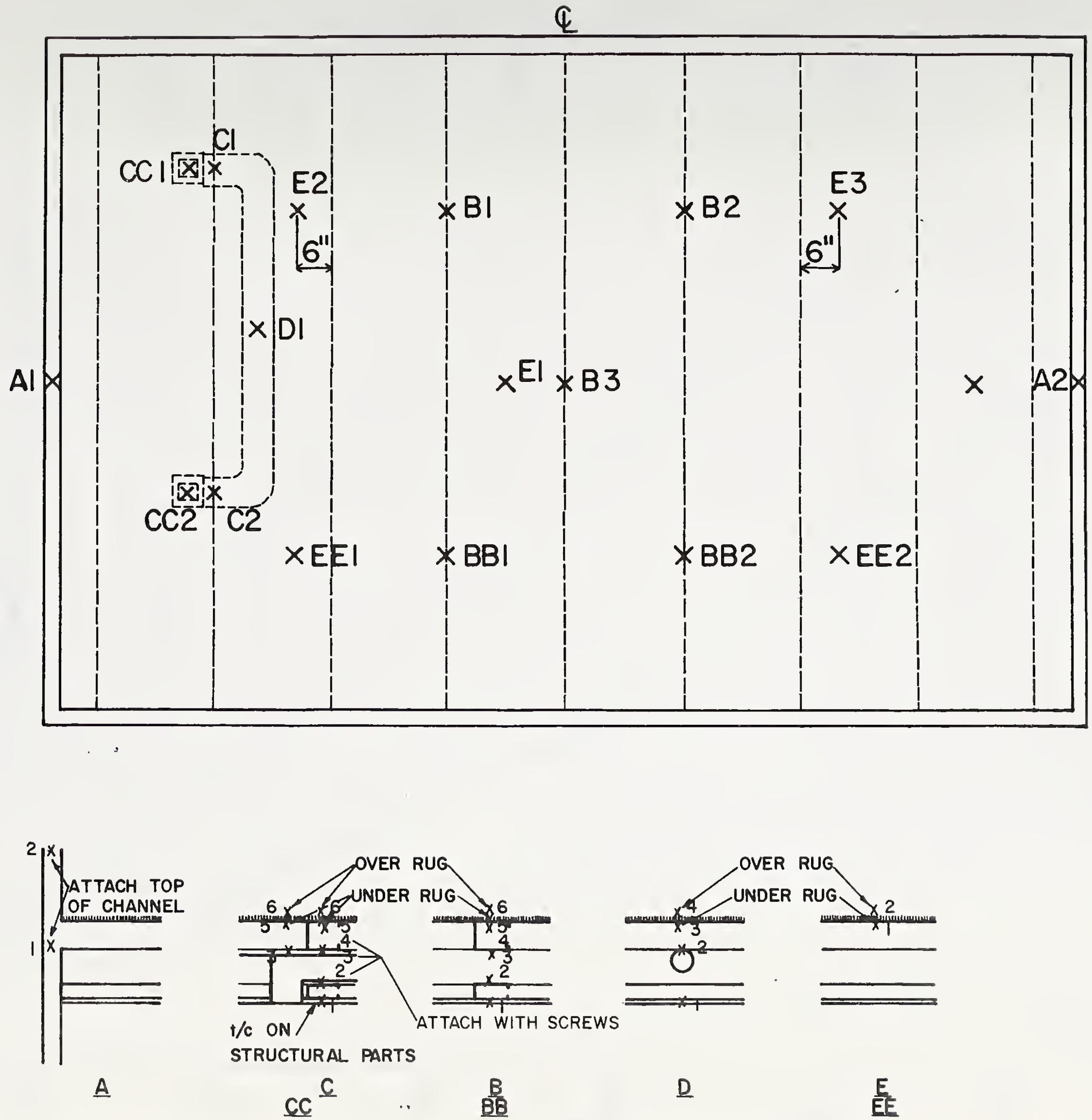


FIG. 7 FLOOR OVER FOUNDATION SPACE: THERMOCOUPLE LOCATIONS ON UNEXPOSED SURFACE



SECTIONS AT THERMOCOUPLE LOCATIONS

FIG. 8 FLOOR-CEILING ASSEMBLY: THERMOCOUPLE LOCATIONS

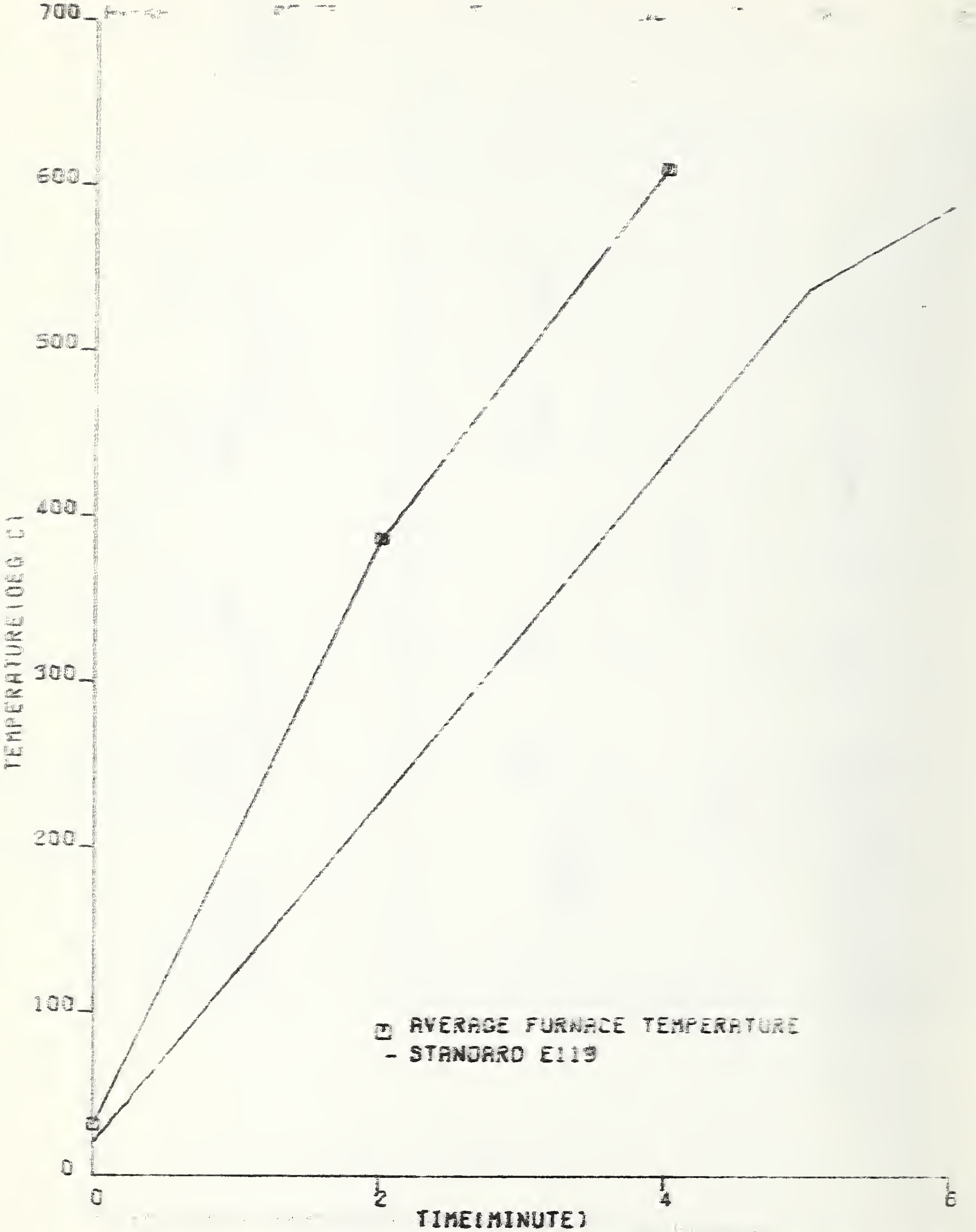


Figure 9 - FLOOR OVER FOUNDATION SPACE - AVERAGE FURNACE TEMPERATURE COMPARED WITH STANDARD E 119 CURVE

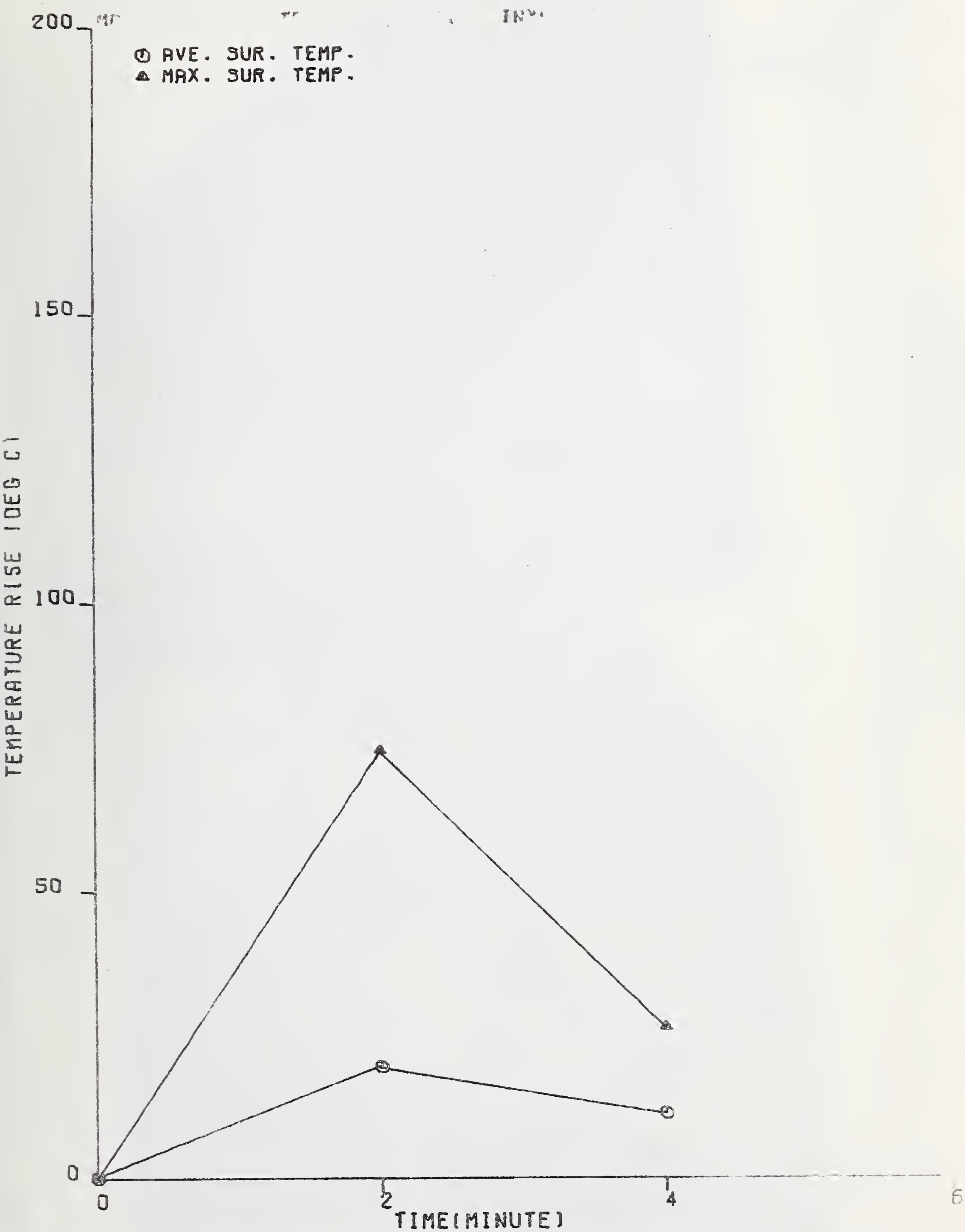


Figure 10 - FLOOR OVER FOUNDATION SPACE - MAXIMUM AND AVERAGE TEMPERATURE RISE OVER VINYL ON THE UNEXPOSED SURFACE

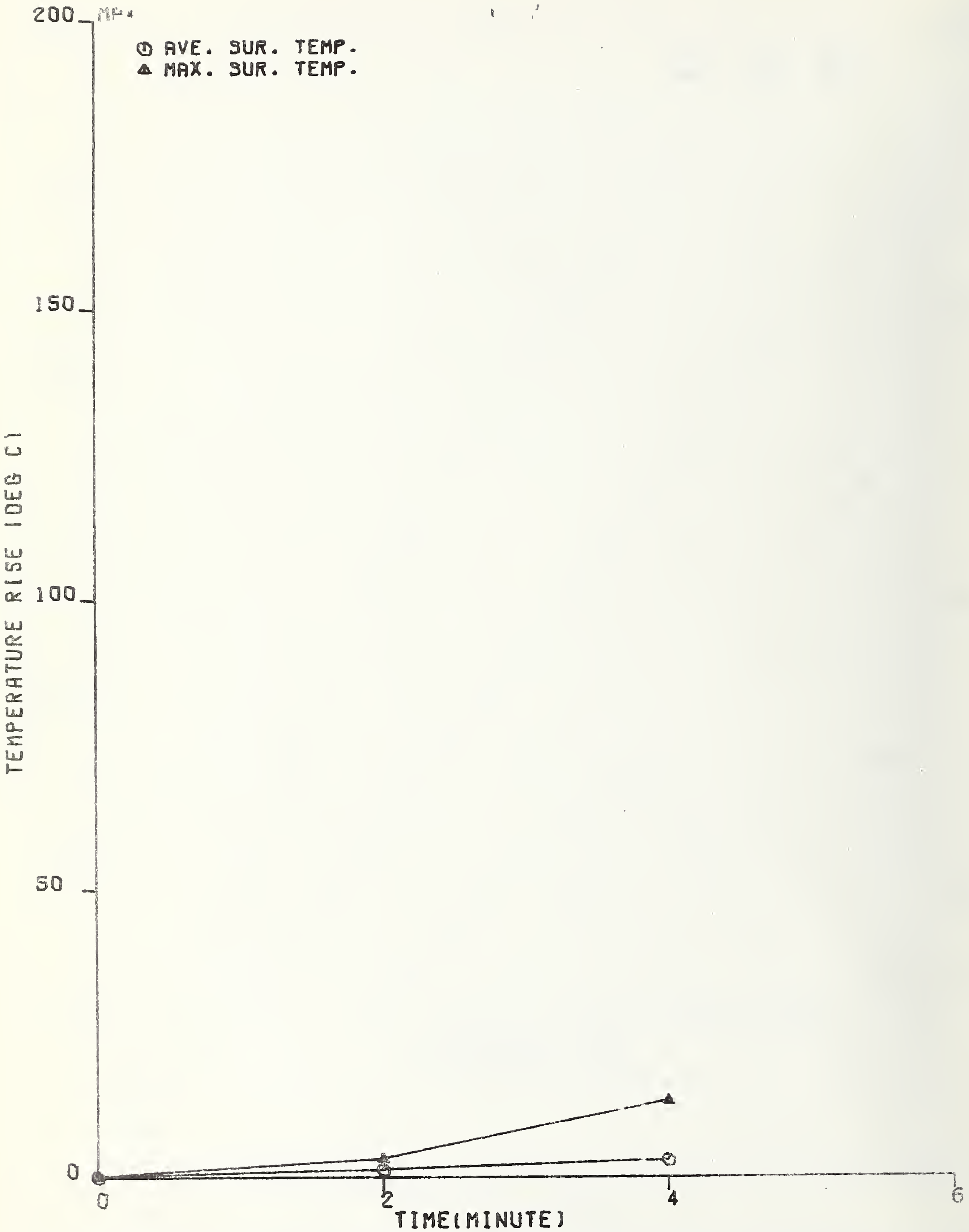


Figure 11 - FLOOR OVER FOUNDATION SPACE - MAXIMUM AND AVERAGE TEMPERATURE RISE OVER CARPET ON THE UNEXPOSED SURFACE

Figure 12 -Floor Over Foundation Space--View of Unexposed Surface of Collapsed Floor

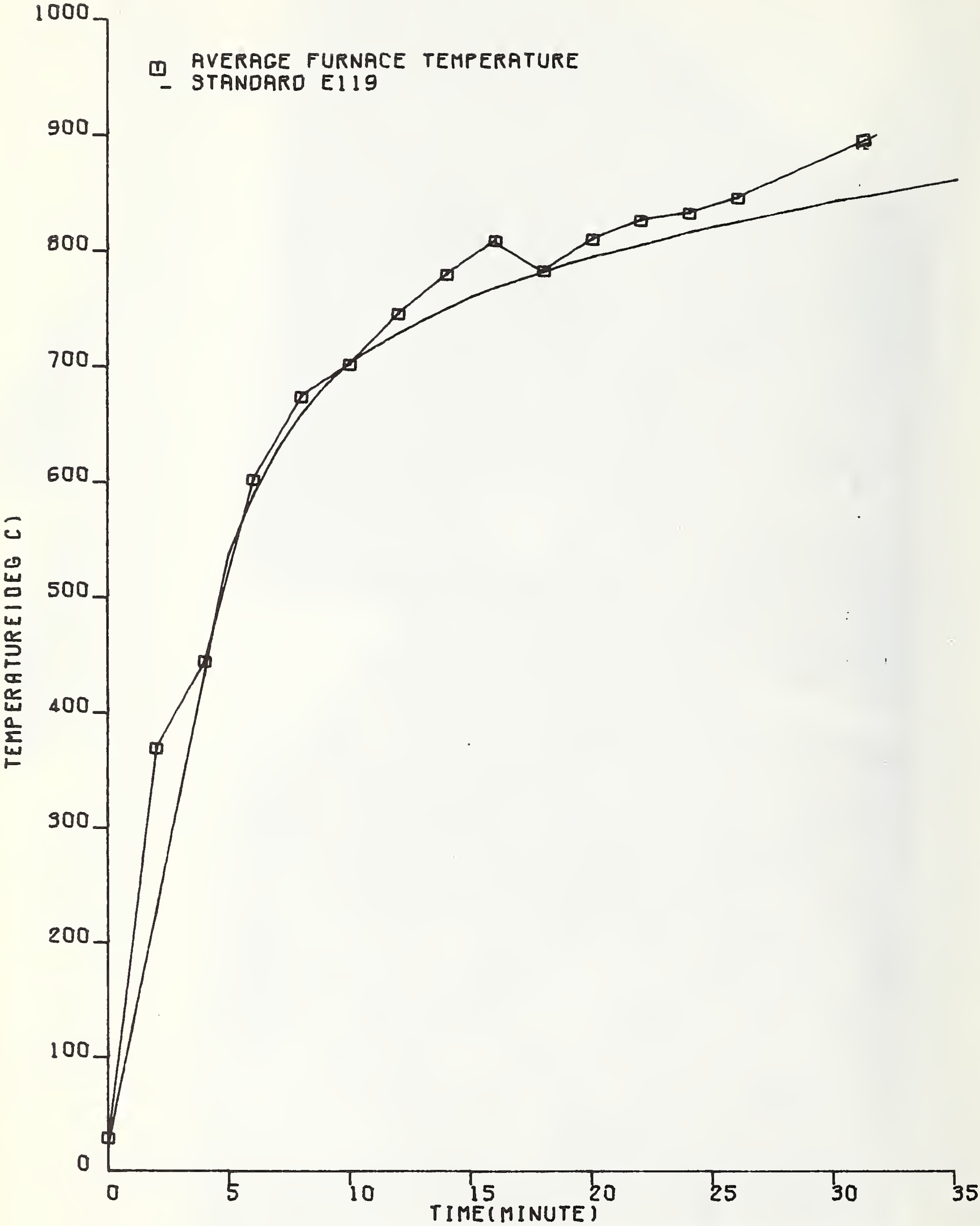


Figure 13 - FLOOR-CEILING ASSEMBLY - AVERAGE FURNACE TEMPERATURE COMPARED WITH STANDARD E 119 CURVE

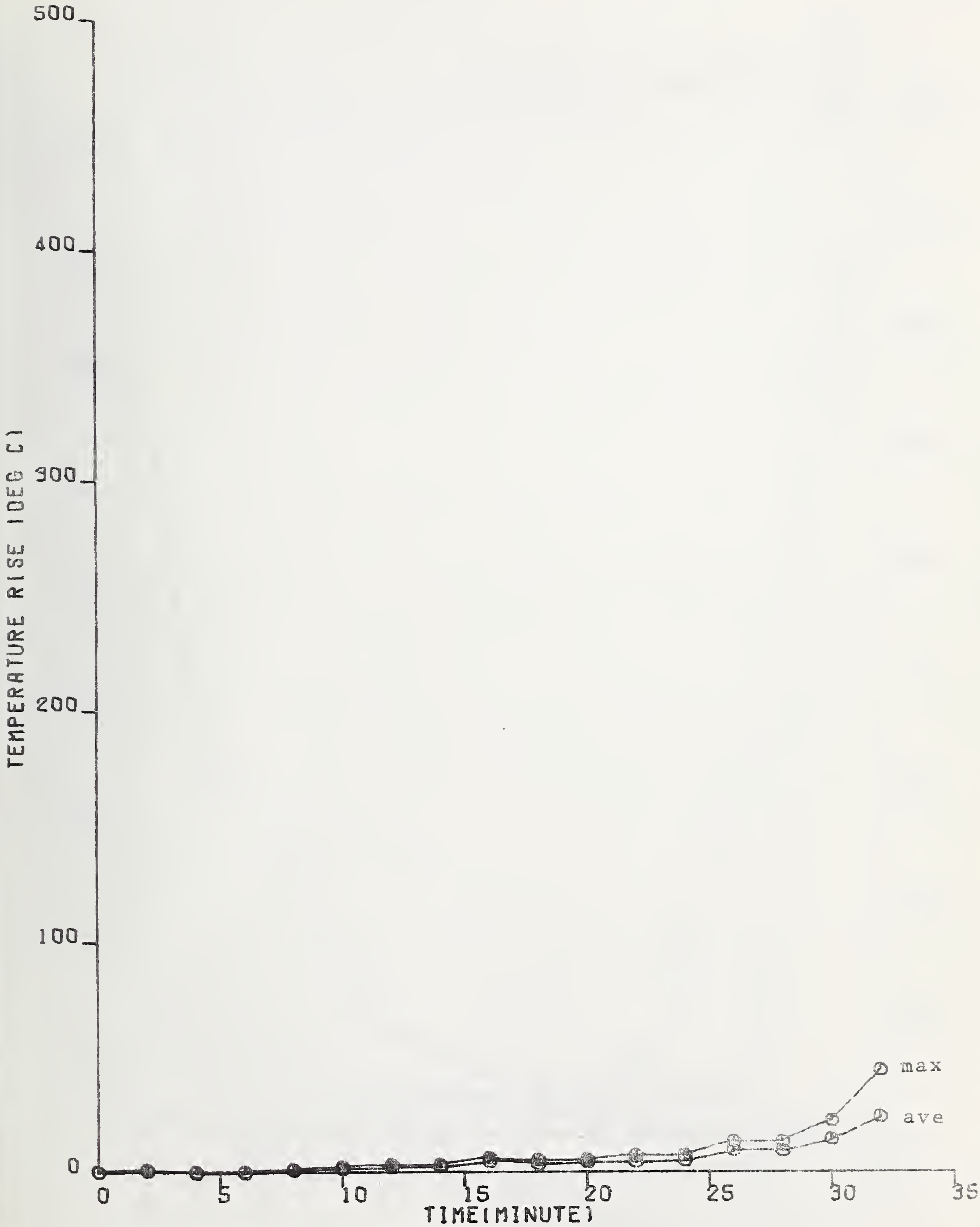


Figure 14 - FLOOR-CEILING ASSEMBLY
Maximum and Average Temperature
Rise on Unexposed Surface (Carpet)

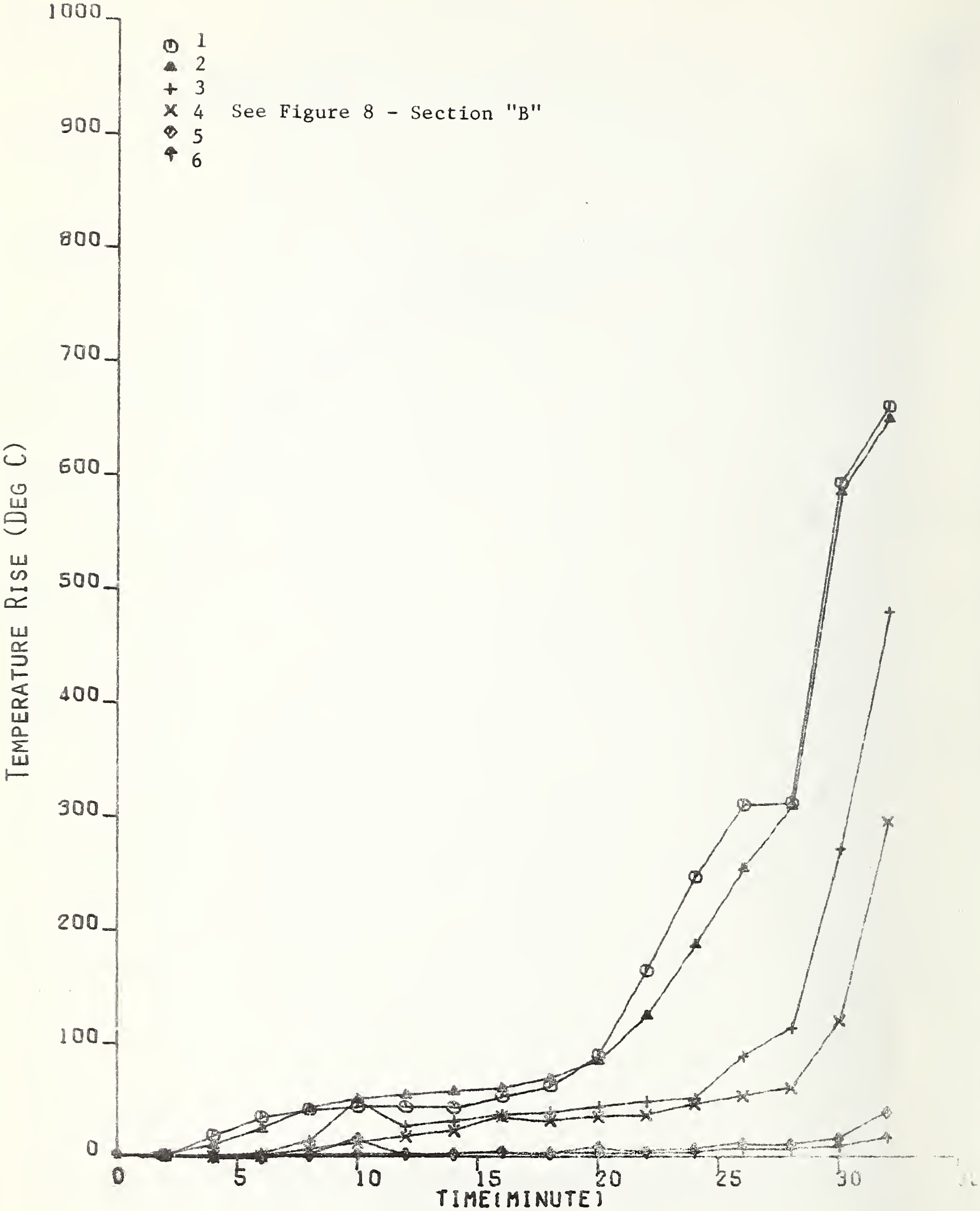


Figure 15 - FLOOR-CEILING ASSEMBLY
Average Temperature Rise
on Steel Joists

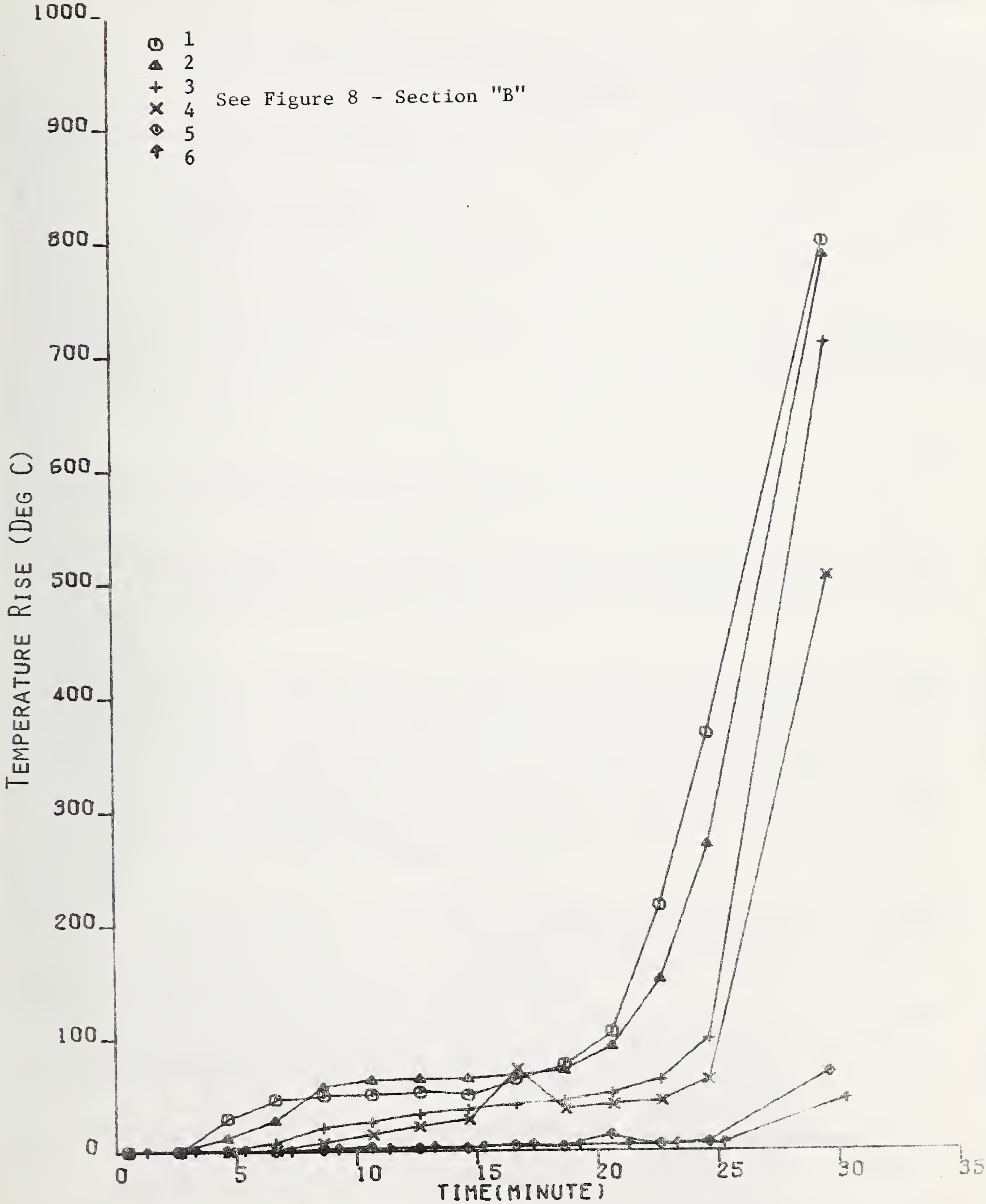


Figure 16 - FLOOR-CEILING ASSEMBLY
Maximum Temperature Rise on
Steel Joists

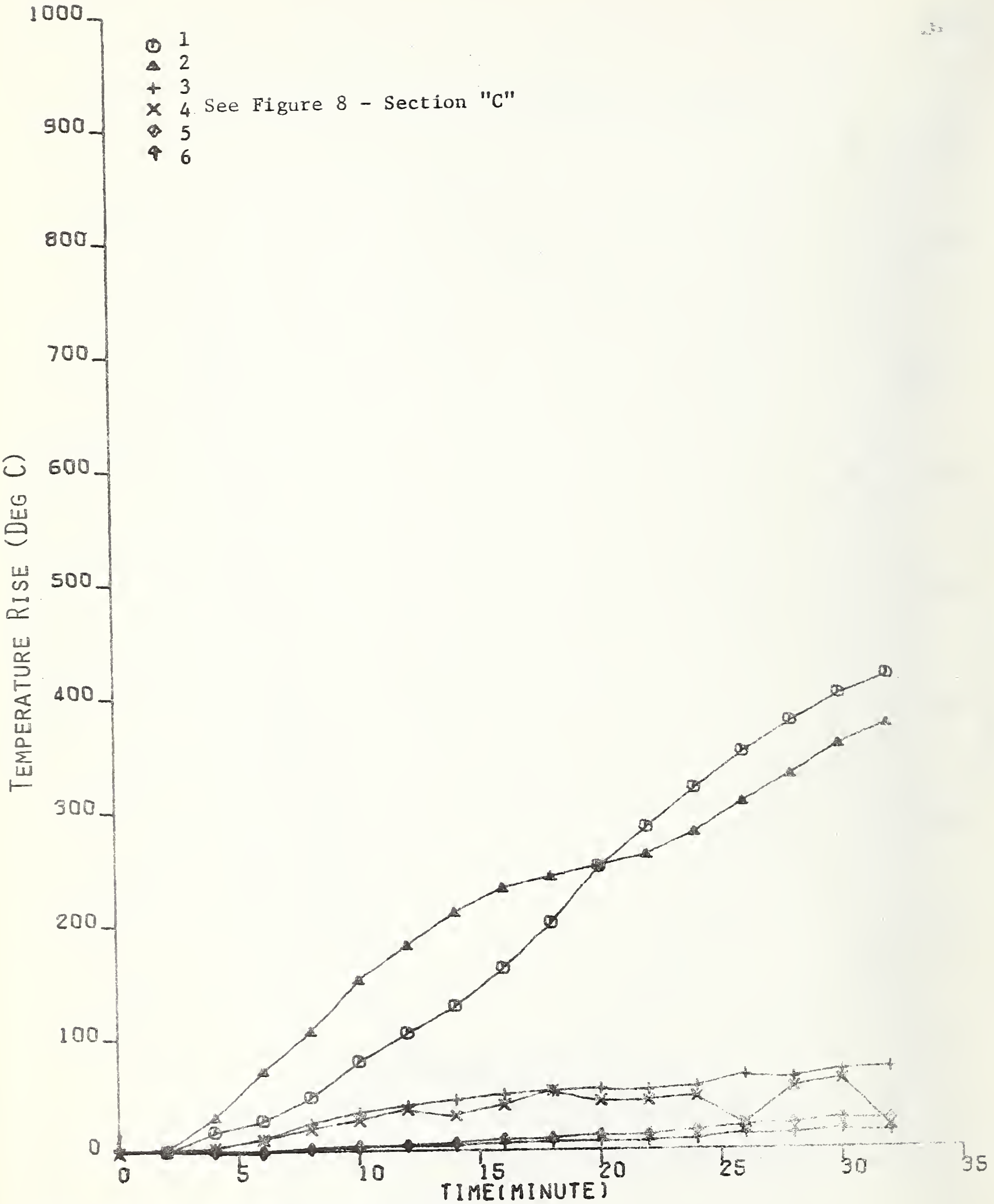


Figure 17 - FLOOR-CEILING ASSEMBLY
Average Temperature Rise
on the Ceiling Ducts

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Fire endurance tests were conducted on two floor/ceiling assemblies intended for use in modular housing. One assembly simulated the combination of the floor of an upper story module with the ceiling assembly of the module beneath; the other assembly, the floor of a first floor module over a ceilingless crawl or foundation space.

The floors were of plywood deck with vinyl or carpet overlay on light gage steel "C" joists. In the floor-ceiling assembly, the ceiling was separately supported on its own joists, contained simulated HVAC* duct work and a layer of glass fiber batt insulation. During the tests which were conducted generally in accordance with the requirements of ASTM E 119-71, Fire Tests of Building Construction and Materials, the floors were loaded to represent the dead weight of structural parts bearing on them and a live load application of 40 psf. The test results are valid only for floors of similar construction loaded at or below the stress level developed by this loading.

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*HVAC - Heating, Ventilation and Air Conditioning

17. KEY WORDS (Alphabetical order, separated by semicolons)
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